DESCRIPTION

OPTICAL PICKUP DEVICE AND OPTICAL DISK APPARATUS

TECHNICAL FIELD

5   The present invention relates to a pickup device which

is capable of, by using a laser light source, optically

recording information (data) to an information storage medium

such as an optical disk, or reproducing information (data)

which is recorded on the information storage medium; and an

10   optical disk apparatus comprising the pickup device.

BACKGROUND ART

In a drive apparatus (optical disk apparatus) which is

capable of performing optical recording/reproduction of

15   information for a disk-shaped optical disk, focusing control

and tracking control are carried out so as to cause the focal

point of a light beam to be placed at a desired position on

the recording surface of a rotating optical disk, by using a

spindle motor or the like. In an optical disk apparatus

20   which is capable of performing recording/reproduction of

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information for an optical disk such as a CD-R or a CD-RW,
tracking control based on a differential push-pull
(Differential Push-Pull: DPP) technique is performed. A DPP
technique generates a tracking error signal by applying

5 calculations to output signals from respective
photodetectors, which are obtained from a main beam and two
sub beams.

Hereinafter, with reference to FIG. 1, a DPP technique
which is performed in the aforementioned optical disk

10 apparatus will be specifically described. FIG. 1 shows the
structure of an optical system 10 in an optical pickup of an
optical disk apparatus. In this optical system 10, a
diffraction grating 202 is disposed in a forward path of a
light beam which is emitted from a laser light source 201.

15 The diffraction grating 202 diffracts the light beam which is
emitted from the laser light source 201 to generate three
beams of light, i.e., 0th order diffracted light (main beam)
and two beams of 1st order diffracted light (sub beam). The
above three beams of light which have been generated through

20 diffraction by the diffraction grating 202 form three light

spots on an optical disk **206** via a beam splitter **203**, a
collimating lens **204**, and an objective lens **205**. Light which
has been reflected by the optical disk **206** is received by a
photodetector **208** via the beam splitter **203** and a detection
lens **207**.

Now, with reference to FIG. **8**, relationship between the
positions of spots of the three beams of light formed on the
optical disk **206** will be described. FIG. **8(a)** is a plan view
schematically showing a relationship of spot positions in a
state where the optical disk **206** is not tilted with respect
to the optical system **10** of FIG. **1**. For reference's sake, a
partial cross section of the optical disk is shown below the
plan view.

As can be seen from FIG. **8(a)**, a spot of the main beam
30 is formed on a predetermined recording track among a
plurality of recording tracks. On both sides of the
recording track which is followed by the main beam **30**, spots
of the sub beams **32** and **33** are formed. More specifically,
spots of the sub beams **32** and **33** are positioned near the
centers of the guide tracks which are on both sides of the

recording track on which the spot of the main beam **30** is positioned. As a result, the positions of the spots of the sub beams **32** and **33** on the optical disk, along the radial direction, are shifted with respect to the position of the spot of the main beam **30** by ± 0.5 track pitches.

FIG. **2** shows a detailed structure of the photodetector **208**. As shown in FIG. **2**, the photodetector **208** includes a main-beam photodetector **301** which is irradiated with the main beam **30** having been reflected from the optical disk **206**, and sub-beam photodetectors **302** and **303** which are respectively irradiated with the sub beams **33** and **32** having been reflected from the optical disk **206**. Through photoelectric conversion, the photodetector **208** outputs electrical signals which are in accordance with the intensity of the light received by each detection section.

The main-beam photodetector **301** is split in four: detection sections **301a**, **301b**, **301c**, and **301d**. The sub-beam photodetector **302** is split in two: detection sections **302e** and **302f**. The sub-beam photodetector **303** is split in two: detection sections **303g** and **303h**.

The split detection sections **301a**, **301b**, **301c**, **301d**, **302e**, **302f**, **303g**, and **303h** output signals A, B, C, D, E, F, G, and H, respectively. By subjecting these signals A to H to calculations, tracking servo error signals are generated. Specifically, based on the signals A to D which are output from the main-beam photodetector **301**, an MPP calculation circuit **304** generates a main push-pull signal (MPP). Based on the signals E to H which are output from the respective sub-beam photodetectors **302** and **303**, an SPP calculation circuit **305** generates a sub push-pull signal (SPP) and a DPP calculation circuit **306** generates a differential push-pull signal (DPP).

The aforementioned calculations performed by the MPP calculation circuit **304**, the SPP calculation circuit **305**, and the DPP calculation circuit **306** are executed in accordance with (eq. 1), (eq. 2), and (eq. 3) shown below.

$$MPP=(A+D)-(B+C) \qquad (eq.\ 1)$$

$$SPP=SPP1+SPP2=(F-E)+(H-G) \quad (eq.\ 2)$$

$$DPP=MPP-\alpha \times SPP$$

$$=(A+D)-(B+C)-\alpha \times \{(F-E)+(H-G)\} \quad \cdots (eq.\ 3)$$

Herein, α is a constant which is determined based on the intensities of the 0th order diffracted light, $+1^{st}$ order diffracted light, and -1st order diffracted light. Although eq. 3 includes the coefficient α, the differential push-pull signal (DPP) is, in the broad sense of the word, a differential signal between the main push-pull signal (MPP) and the sub push-pull signal (SPP).

According to the aforementioned tracking servo method, as shown in FIG. 2, the positioning of optical elements such as the diffraction grating **202**, the laser light source **201**, the photodetector **208** is set so that the respective beams will be positioned on the centers of the split lines of the photodetectors **301**, **302**, and **303**.

FIG. 3 shows signal waveforms **401**, **402**, and **403** of the main push-pull signal (MPP), the sub push-pull signal (SPP), and the differential push-pull signal (DPP) in the case where the aforementioned ideal positioning is realized.

As is clear from FIG. 3, the phase of the SPP waveform **402** is shifted by π rad (180°) with respect to the phase of the MPP waveform **401**, the two waveforms being of inverted

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relationship. Such a relationship is obtained because, as shown in FIG. **8(a)**, the spots of the sub beams **32** and **33** are positioned not on recording tracks but on guide tracks, so that their signal polarities are inverted.

5   Since the polarity of the SPP waveform **402** and the polarity of the MPP waveform **401** are opposite, the phase of the DPP waveform **403** which is obtained in accordance with eq. (3) has the same phase as that of the MPP waveform **401**.

In the case where the optical disk **206** is not tilted, as
10   shown in FIG. **8(a)**, the light spot of the main beam **30** upon the optical disk **206** is on a track center at the position indicated by reference numeral **"40"** in FIG. **3**. The DPP waveform **403** is calibrated and set so as to indicate a zero value at this time.

15   In the DPP technique, there is performed a tracking control for causing the entire objective lens or the entire optical pickup device to move along a radial direction of the optical disk **206** in such a manner that the DPP waveform **403** exhibits a zero value. Since the light spot that is the
20   target of the tracking control is the light spot of the main

beam, the light spot of the main beam will be abbreviated as the "light spot" in the following descriptions, for simplicity.

The above-described conventional optical pickup device is disclosed in, for example, Japanese Laid-Open Patent Publication No. 2001-307351.

In the case where the optical disk **206** or the objective lens **205** is tilted along a radial direction of the optical disk, the MPP, SPP, and DPP signal waveforms change to an MPP waveform **501**, an SPP waveform **502**, and a DPP waveform **503**, respectively, as shown in FIG. **4**. This is because, if the optical disk **206** is tilted as shown in FIG. **8(b)**, the main beam **30** and the sub beams **32** and **33** will be obliquely incident on a recording track/guide tracks on the optical disk **206**. As a result, a phase difference occurs between the MPP waveform **501** and the SPP waveform **502**. Assume that a phase difference of ϕ emerges between the MPP waveform **501** and the SPP waveform **502**. In this case, the phase of the DPP waveform **503** is shifted from the phase of the ideal signal waveform, which would exhibit a zero value when the light

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spot is on a track center, and has a phase difference with a magnitude of "ϕ". Therefore, when a tracking control is performed based on such a DPP waveform 503, the DPP waveform 503 will indicate a zero value at a position indicated by reference numeral "51" in FIG. 4, and therefore the actual light spot will be controlled to a position which is shifted by a distance Δ, which corresponds to the phase difference ϕ, from the track center (i.e., a position indicated by reference numeral "50"). This distance Δ will be referred to as an "off-tracking amount" of the light spot position. Although the off-tracking amount Δ is described in relation to the DPP waveform 503 in FIG. 4, the actual off-tracking amount is a distance between the light spot position of the main beam and a recording track center on the optical disk.

With the DPP signal (tracking error signal) which has incurred a phase shift as above, it is impossible to control the position of the light spot to be accurately on a track center, so that the tracking control becomes unstable. This results in an off-tracking, i.e., deviation of a light spot on an optical disk from a track center, whereby the

recording/reproduction characteristics of the optical disk apparatus are deteriorated.

The present invention has been made in order to solve the above problems, and is aimed at providing: an optical pickup device capable of correcting an off-tracking which is ascribable to a phase shift of a DPP signal waveform, even when an optical disk or an objective lens is tilted along a radial direction of the optical disk, so that stable tracking control can be performed; and, an optical disk apparatus comprising such an optical pickup device.

DISCLOSURE OF INVENTION

An optical disk apparatus according to the present invention comprises: a motor for rotating an optical disk; a light source; diffraction means for diffracting a portion of light emitted from the light source to form a main beam of 0th order light and a pair of sub beams composed of $+1^{st}$ order light and -1st order light which are formed on both sides of the 0th order light; an objective lens for converging the main beam and the pair of sub beams onto the optical disk;

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light receiving means for receiving the main beam and the sub beams reflected from the optical disk, and outputting electrical signals through photoelectric conversion; a calculation section for, based on the electrical signals output from the light receiving means, providing a main push-pull signal MPP, a sub push-pull signal SPP, and a differential signal between the main push-pull signal MPP and the sub push-pull signal SPP; and phase difference detection means for detecting a phase difference between the main push-pull signal MPP and the differential signal, wherein, in accordance with an output from the phase difference detection means, an offset is applied in a tracking control of the main beam with respect to the optical disk to compensate for an off-tracking caused by a phase shift of the differential signal.

In a preferred embodiment, the differential signal is a differential push-pull signal DPP.

In a preferred embodiment, the light receiving means comprises: a main-beam photodetector having four split photoelectric conversion sections for receiving the main beam

reflected from the optical disk; a first sub-beam photodetector having two split photoelectric conversion sections for receiving one of the pair of sub beams; and a second sub-beam photodetector having two split photoelectric

5 conversion sections for receiving the other of the pair of sub beams, and the calculation section further comprises: first calculation means for determining the main push-pull signal MPP=(A+D)-(B+C), based on signals A, B, C, and D obtained respectively from the four split photoelectric

10 conversion sections of the main-beam photodetector; second calculation means for determining the sub push-pull signal SPP=(F-E)+(H-G), based on signals E and F obtained respectively from the two split photoelectric conversion sections of the first sub-beam photodetector and on signals G

15 and H obtained respectively from the two split photoelectric conversion sections of the second sub-beam photodetector; and third calculation means for determining the differential push-pull signal DPP=MPP- α ×SPP (where α is a constant), based on outputs from the first calculation means and the

20 second calculation means.

In a preferred embodiment, signal amplitude calculation means for adjusting amplitudes of the main push-pull signal MPP and/or the sub push-pull signal SPP so that the amplitude of the main push-pull signal MPP and the amplitude of the sub push-pull signal SPP become equal; signal summation means for calculating a sum of the main push-pull signal MPP and the sub push-pull signal SPP which are output from the signal amplitude calculation means; and phase difference calculation means for, based on an output from the signal summation means, calculating a phase difference between the main push-pull signal MPP and the sub push-pull signal SPP are comprised.

An optical pickup device according to the present invention comprises: a light source; diffraction means for diffracting a portion of light emitted from the light source to form a main beam of 0th order light and a pair of sub beams composed of $+1^{st}$ order light and -1st order light which are formed on both sides of the 0th order light; an objective lens for converging the main beam and the pair of sub beams onto the optical disk; light receiving means for receiving

the main beam and the sub beams reflected from the optical

disk, and outputting electrical signals through photoelectric

conversion; a calculation section for, based on the

electrical signals output from the light receiving means,

5   providing a main push-pull signal MPP, a sub push-pull signal

SPP, and a differential signal between the main push-pull

signal MPP and the sub push-pull signal SPP; and phase

difference detection means for detecting a phase difference

between the main push-pull signal MPP and the sub push-pull

10   signal SPP, wherein, in accordance with an output from the

phase difference detection means, an offset is applied in a

tracking control of the main beam with respect to the optical

disk to compensate for an off-tracking caused by a phase

shift of the differential signal.

15   A driving method for an optical disk according to the

present invention comprises: a step of converging a main beam

and a pair of sub beams onto an optical disk and outputting

electrical signals based on the main beam and the sub beams

reflected from the optical disk; a step of, based on the

20   electrical signals, providing a main push-pull signal MPP, a

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sub push-pull signal SPP, and a differential signal between the main push-pull signal MPP and the sub push-pull signal SPP; and a step of detecting a phase difference between the main push-pull signal MPP and the differential signal, wherein, based on the phase difference, an offset is applied in a tracking control of the main beam with respect to the optical disk to compensate for an off-tracking caused by a phase shift of the differential signal.

In a preferred embodiment, the differential signal is a differential push-pull signal DPP.

In a preferred embodiment, the step of providing the differential signal comprises: a step of determining the main push-pull signal MPP=(A+D)-(B+C), based on signals A, B, C, and D obtained respectively from four split photoelectric conversion sections of a main-beam photodetector; a step of determining the sub push-pull signal SPP=(F-E)+(H-G), based on signals E and F obtained respectively from two split photoelectric conversion sections of a first sub-beam photodetector and on signals G and H obtained respectively from two split photoelectric conversion sections of a second

sub-beam photodetector; and a step of determining the differential push-pull signal DPP=MPP-α ×SPP (where α is a constant).

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a diagram showing the structure of an optical system used in an optical pickup device.

FIG. 2 is a diagram showing the structure of a photodetector used in an optical pickup device.

FIG. 3 is a diagram showing signal waveforms obtained by a DPP technique.

FIG. 4 is a diagram showing an MPP waveform and an SPP waveform having a phase difference, and a DPP waveform.

FIG. 5 is a diagram showing the structure of an optical pickup device (first embodiment) of an optical disk apparatus according to the present invention.

FIG. 6 is a diagram showing a DPP waveform having a phase shift, and a DPP waveform which has been subjected to an off-tracking correction.

FIG. 7(a) is a diagram showing the structure of a phase

difference detection circuit in an optical pickup device (second embodiment) of an optical disk apparatus according to the present invention. FIG. **7(b)** is a diagram showing the waveforms of signals which are generated through calculations in the second embodiment.

FIGS. **8(a)** and **(b)** are diagrams schematically showing a positioning relationship between light spots of three beams **30, 32,** and **33** on an optical disk.

FIG. **9** is a diagram showing the general structure of an optical disk apparatus according to the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Hereinafter, embodiments of the present invention will be described with reference to the figures.

(Embodiment 1)

First, FIG. **9** is referred to. FIG. **9** is a diagram showing the general structure of an optical disk apparatus according to the present embodiment.

The illustrated optical disk apparatus comprises: a spindle motor **902** for rotating an optical disk **206;** an

optical pickup device **904** which optically accesses a desired

track on the optical disk **206**; and a servo system **906** for

controlling the number of revolutions of the spindle motor

902 and the position of the pickup device **904**. Moreover,

5   this optical disk apparatus comprises a signal processing

section **908** for processing signals which are output from the

optical pickup device **904**, as well as a video decoder **910** and

an audio decoder **912** for decoding a video signal and an audio

signal, respectively, which are output from the signal

10 processing section **908**. The specific structures of the

signal processing section **908**, the video decoder **910**, and the

audio decoder **912** are identical to their known structures.

Although FIG. **9** illustrate constituent elements which

are necessary for a reproduction operation of reading data

15 which is recorded on the optical disk **206**, constituent

elements (not shown) for recording data onto the optical disk

206 may be comprised.

Next, FIG. **5** is referred to. FIG. **5** shows the structure

of the optical pickup device **904** in the present embodiment.

20   The optical pickup device **904** shown in FIG. **5** comprises

an optical system **10**, a phase difference detection circuit **101**, an off-tracking correction amount calculation circuit **102**, and an objective lens driving circuit **103**. The optical system **10** of the present embodiment is similar to the conventional optical system shown in FIG. **1**, although an objective lens driving device **104** not shown in FIG. **1** is shown in FIG. **5**. The objective lens driving device **104** drives the objective lens **205** along a radial direction of the optical disk **206**. The structure and operation of the optical system **10** are similar to those of the optical system **10** shown in FIG. **1**, and the structure of the photodetector **208** is also similar to the structure shown in FIG. **2**, and therefore the detailed descriptions of their structures and operations will not be repeated here.

In the present embodiment, in order to eliminate the aforementioned off-tracking, the optical pickup device **904** comprises the phase difference detection circuit **101** and the off-tracking correction amount calculation circuit **102**, and the objective lens driving circuit **103** controls the driving of the objective lens **205** in an appropriate manner.

Hereinafter, with reference to FIG. 5, the phase difference detection circuit **101**, the off-tracking correction amount calculation circuit **102**, and the objective lens driving circuit **103** will be described.

5   The phase difference detection circuit **101** of the present embodiment functions as a phase difference detection means for detecting a difference in phase between the waveform of an MPP signal and the waveform of an SPP signal obtained from the photodetector **208** in the optical system **10** of the optical pickup device **904**. The phase difference detection circuit **101** simultaneously monitors the MPP signal waveform and the SPP signal waveform, and compares them to detect a phase difference therebetween. The phase difference detection circuit **101** as such can be realized by providing, for example, a circuit which monitors the time at which the output of each of the MPP signal and the SPP signal becomes zero and detects a difference between such times, and a circuit which monitors the frequencies of the MPP signal waveform and the SPP signal waveform and calculates the amount of phase difference corresponding to this time

difference. Such a circuit can be realized by hardware, software, or a combination of hardware and software. For example, since a servo processor (IC chip) incorporated in a DVD player or recorder has a function of measuring the phases

5 of signal waveforms, the phase difference detection circuit 101 can be realized by utilizing at least a portion of this servo processor.

The phase difference detection circuit 101 outputs a signal representing the detected phase difference, and sends

10 the signal to the off-tracking correction amount calculation circuit 102.

On the basis of the "phase difference" detected by the phase difference detection circuit 101, the off-tracking correction amount calculation circuit 102 calculates the

15 amount of any off-tracking that occurs, and outputs a signal which represents a off-tracking amount for correction. This signal is sent to the objective lens driving circuit 103. The aforementioned "phase difference" is a phase difference between the aforementioned MPP signal and SPP signal, and

20 occurs when the optical disk or the objective lens is tilted

along a radial direction of the optical disk, for example. A method for calculating an off-tracking amount based on a detected "phase difference" will be described later.

Based on the signal which is output from the off-tracking correction amount calculation circuit **102**, the objective lens driving circuit **103** is able to drive the objective lens driving device **104** so as to move the objective lens **205** along a radial direction of the optical disk.

Thus, in the present embodiment, in accordance with a signal representing a phase difference which is output from the phase difference detection circuit **101**, an offset is applied in the tracking control of the objective lens **205**, whereby any off-tracking caused by a phase shift of the DPP signal as shown in FIG. **4** is compensated for.

Hereinafter, the correction operation for tracking control will be described more specifically.

The off-tracking amount correction calculation circuit **102** shown in FIG. **5** receives from the phase difference detection circuit **101** a signal representing a phase difference (=phase shift amount of the DPP signal) ϕ

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detected between the MPP signal waveform **501** and the SPP

signal waveform **502** as shown in FIG. **4**, and then calculates

an off-tracking amount Δ according to the following

equation.

5 $\qquad \Delta = T \times \phi / 2\pi$ $\qquad\qquad$ (eq. 4)

Herein, T is a track pitch of the optical disk.

The off-tracking amount correction calculation circuit

102 outputs a signal representing the off-tracking amount Δ

which has been calculated based on (eq. 4), and sends the

10 signal to the objective lens driving circuit **103** in FIG. **5**.

The objective lens driving circuit **103** drives the

objective lens driving device **104** to move the objective lens

205 along a radial direction of the optical disk. At this

time, the determination as to whether the direction of the

15 movement should be toward the outer periphery or the inner

periphery of the optical disk is to be made so that the off-

tracking will be cancelled. Specifically, a direction of

movement for reducing an off-tracking amount is previously

determined in accordance with whether the MPP signal being

20 output during tracking control is positive or negative in the

DC level. The direction of movement is to be determined in accordance with whether the MPP signal is positive or negative in the DC level.

Next, with reference to FIG. 6, the magnitude of off-tracking amount will be described.

FIG. 6 shows a DPP signal waveform 601 in an ideal state where the optical disk or the objective lens is not tilted along a radial direction of the optical disk, and the DPP signal waveform 503 in a state where the optical disk or the objective lens is tilted along a radial direction of the optical disk.

In the case where a phase difference ϕ has occurred due to a tilt of the optical disk or the like as in the DPP signal waveform 503, if the conventional tracking control is performed as it is, the position of the light beam spot will be controlled to a position corresponding to a point X, at which the DPP signal waveform 503 has a zero-cross. As a result, the light spot is controlled to a position 61 which is shifted (off-tracked) from a track center. However, in the present embodiment, the off-tracking amount Δ is

corrected so that a tracking control is performed so as to retain the light beam spot at a position **60** corresponding to a point **Y** of the DPP signal waveform **503**.

The reason why the off-tracking amount Δ corresponding to the phase difference ϕ is expressed as in eq. 4 is that $\Delta/T = \phi/2\pi$ holds true when a track pitch corresponding to the radial direction period of the DPP signal waveform **503**, **601** is **T**, as shown in FIG. 6.

Assume that the phase difference detected by the phase difference detection circuit **101** has a magnitude which is represented as $\phi = \pi/4$ (radian), for example. At this time, if the optical disk to be subjected to recording or reproduction is a DVD-R, the track pitch is T=0.74(μm), so that the off-tracking amount Δ calculated from (eq. 4) is $(0.74 \times \pi/4)/2\pi = 0.0925(\mu m)$.

In this case, the phase difference detection circuit **101** determines the direction of corrected off-tracking based on whether the aforementioned phase difference is positive or negative, and outputs to the objective lens driving circuit **103** a signal representing the aforementioned corrected off-

track amount and correction direction. Based on this signal, the objective lens driving circuit **103** drives the objective lens driving device **104** to move the objective lens **205** in the proper direction, along a radial direction of the optical

5 disk, by the corrected off-tracking amount. In this manner, according to the present embodiment, even if a phase difference occurs between the MPP signal and the SPP signal because the optical disk **206** or the objective lens **205** has tilted along a radial direction of the optical disk, for

10 example, the phase shift of the DPP signal which may occur responsive to this phase difference can be compensated for. As a result, a stable tracking control is enabled, and the recording/reproduction performance of the optical pickup device **904** can be improved.

15 Instead of adopting the above-described structure according to the present embodiment, a DPP phase calculation means which corrects a phase shift in the DPP signal in accordance with the output from the phase difference detection circuit **101** may be used. In this case, the DPP

20 phase calculation means applies an offset of phase ϕ, in the

direction of an arrow **62**, to the DPP signal waveform **503** shown in FIG. **6**. As a result, an ideal DPP signal waveform **601** which is free of phase shift can be output. In this case, since a usual tracking control centered which is around

5 a point Z (at which the DPP signal waveform **601** has a zero-cross) is performed, the recording/reproduction performance of the optical pickup device can be improved with a simple circuit structure. Note that the offset for such compensation is to be varied in accordance with the measured

10 phase shift ϕ, rather than being a constant value.

Moreover, the light receiving means in the present embodiment is composed of a four-split photodetector as the main-beam photodetector and two-split photodetectors as the sub-beam photodetectors. However, the light receiving means

15 according to the present invention is not limited to such photodetectors. For example, the number of splits in each sub-beam photodetector may be increased from two to four. In that case, it would be possible to generate a focus error signal by using the signals which are output from the two

20 sub-beam photodetectors.

Moreover, the present invention can be broadly applied to an optical disk apparatus which utilizes a differential push-pull (DPP) technique as a tracking method. The specific structure of the photodetector, e.g., the number of splits and the manner of splitting, is not limited to that in the present embodiment. Furthermore, applications to an optical disk apparatus utilizing a three-beam technique would also be possible.

In the present embodiment, the objective lens 205 (FIG. 5) is driven for performing tracking control. Instead, the optical pickup device itself may be moved along a radial direction of the optical disk 206, by using a mechanism for driving the optical pickup device 904. Also, the structure of the optical system 10 of the optical pickup is not limited to that which is shown in FIG. 1. Based on the outputs from the photodetector 208, calculations similar to the calculations performed by the MPP calculation circuit 304, the SPP calculation circuit 305, and the DPP calculation circuit 306 shown in FIG. 2 may be performed externally to the photodetector 208 to generate an MPP signal, an SPP

signal, and a DPP signal.

(Embodiment 2)

Next, with reference to FIGS. 7(a) and (b), a second embodiment of the optical disk apparatus according to the present invention will be described. FIG. 7(a) shows an exemplary internal structure of the phase difference detection circuit 101. Other than the phase difference detection circuit 101, the structure of the optical pickup device of the present embodiment is identical to the structure of the optical pickup device 904 of Embodiment 1.

The phase difference detection circuit 101 of the present embodiment comprises a signal amplitude calculation circuit 701, a signal summation circuit 702, and a phase difference calculation circuit 703.

The signal amplitude calculation circuit 701 performs calculations (conversion) for an MPP signal and/or an SPP signal so that the amplitudes of the MPP signal waveform and the SPP signal waveform become electrically equal to each other, and outputs the MPP signal and the SPP signal whose amplitudes have become equal.

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The signal summation circuit **702** receives the MPP signal and the SPP signal which are output from the signal amplitude calculation circuit **701**, calculates a sum of both signals, and outputs the sum as a sum signal SumPP. The phase difference calculation circuit **703** receives the sum signal SumPP which is output from the signal summation circuit **702**, and based on the amplitude of the sum signal SumPP, determines the phase difference between the MPP signal and the SPP signal according to a specific calculation formula.

Referring to FIG. **7(b)**, a specific procedure of phase difference detection will be described. FIG. **7(b)** shows waveforms **704**, **705**, and **706** of the MPP signal, the SPP signal, and the sum signal SumPP, respectively, generated by the above calculation circuits.

The MPP signal and SPP signal which are output from the DPP calculation circuit **306** shown in FIG. **2** are first input to the signal amplitude calculation circuit **701**. Then, the signal amplitude calculation circuit **701** outputs an MPP signal and an SPP signal which have been converted so as to have electrically equal amplitudes. Herein, by using the

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phase difference ϕ occurring between the MPP signal and the SPP signal, time t(s), and angular velocity ω (1/s) of the signal, the MPP signal and the SPP signal can be expressed by the following equations.

5        $MPP=A \cdot \sin(\omega \cdot t)$ (eq. 5)

$SPP=-A \cdot \sin(\omega \cdot t - \phi)$ (eq. 6)

Herein, A is a constant representing amplitude.

The MPP signal and SPP signal after conversion are input to the signal summation circuit **702**, and the signal summation

10   circuit **702** calculates a sum signal SumPP obtained by adding the MPP signal and the SPP signal, and outputs the result of the calculation to the phase difference calculation circuit **703**.

The sum signal SumPP is expressed by (eq. 7) below,

15   based on (eq. 5) and (eq. 6).

$SumPP=MPP+SPP=A \cdot \sin(\omega \cdot t) - A \cdot \sin(\omega \cdot t - \phi) = A \cdot (2-2\cos\phi)^{1/2} \cdot \sin(\omega \cdot t + \delta)$ $\cdots$ (eq. 7)

Herein, δ is a constant representing phase.

From (eq. 7), the amplitude of the signal waveform of

20   the sum signal SumPP which is input to the signal summation

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circuit **703** is a function of ϕ as expressed by $A \cdot (2-2\cos \phi)^{1/2}$.

Therefore, by detecting the amplitude of the signal waveform of the sum signal SumPP which is input to the phase

5 difference calculation circuit **703**, and subjecting it to calculations, the phase difference ϕ can be obtained. In other words, in the phase difference calculation circuit **703**, an amplitude B of the signal waveform of the SumPP which is monitored can be expressed by (eq. 8) below.

10      $B=A \cdot (2-2\cos \phi)^{1/2}$ (eq. 8)

As is clear from (eq. 8), by monitoring the values (magnitude) of the amplitude A and amplitude B of the respective signal waveforms, the value of the phase difference ϕ is obtained. A signal (which may be of an

15 arbitrary format, e.g., analog or digital) representing the value of the phase difference ϕ calculated in the above manner is sent to the offset correction amount calculation circuit **102** in FIG. **5**, and a correction of the offset amount is performed. Specifically, in a manner similar to the

20 operation which has been described with respect to the

optical pickup device of Embodiment 1, the off-tracking

amount correction calculation circuit **102** calculates a

corrected off-track amount according to (eq. 4), and sends a

signal (which may be of an arbitrary format, e.g., analog or

5   digital) representing this off-tracking amount to the

objective lens driving circuit **103**.   Based on this signal,

the objective lens driving circuit **103** drives the objective

lens driving device **104**, moves the objective lens **205** along a

disk radial direction, and corrects the off-tracking.

10   Thus, in accordance with the structure of the present

embodiment, if there occurs an off-tracking that is

ascribable to a phase difference ϕ between the MPP signal

and the SPP signal, which would occur when the optical disk

or the objective lens is tilted along a radial direction of

15   the optical disk, the phase difference ϕ is detected, and a

tracking control is performed which is corrected in such a

manner as to cancel an off-tracking amount which is

calculated by using the detected phase difference ϕ .   As a

result, a stable tracking control is enabled, and the

20   recording/reproduction performance of the optical pickup

device can be improved.

The calculations of the MPP signal and the SPP signal performed in order to calculate the aforementioned phase difference ϕ can be easily performed by using calculation circuits comprised in an ordinary optical pickup device (calculation circuits for the processing of signals from an optical disk, servo control, and the like). Thus, without having to newly provide a phase detection circuit for the signal waveforms, the above can be realized with a simple circuit structure, and a stable tracking control can be attained at a low cost.

The angle of a tilt of an optical disk along a radial direction as shown in FIG. **8(b)** changes in accordance with the positioning relationship between the optical disk and the optical pickup. Moreover, the tilt angle may rapidly fluctuate in a periodic manner while the optical disk is rotated by a motor. According to the present invention, in response to such dynamic fluctuations of the tilt angle, the offset to be applied to tracking control can be rapidly changed, whereby off-tracking can be reduced in a dynamic and

adaptive manner.   The reason why such dynamic compensation is possible is that the optical disk apparatus of the present invention compensates for phase shifts in signal waveforms through calculations.

5   Note that, in the case where the changes in phase difference ϕ as detected in the present invention are periodic, once the period is ascertained, then there is no need to always perform the operation of measuring the phase difference ϕ in real time.   The periodically-changing

10 magnitude may be predicted to compensate for off-tracking. By doing so, it will be possible to reduce the calculation amount.

Furthermore, although the calculation processes which are necessary for off-tracking compensation are performed

15 inside the optical pickup device in the above embodiments, a part or whole of such calculations may be performed in any section in the optical disk apparatus other than the optical pickup device (e.g., a calculation section in an IC chip such as a servo processor).   Such a servo processor is provided

20 in, for example, the servo system **906** shown in FIG. **9**.

In accordance with the optical disk apparatus of the present invention having the above structure, during data recording/reproduction operations, a main beam and a pair of sub beams are converged onto an optical disk, and based on

5 the main beam and the sub beams reflected from the optical disk, a step of determining a main push-pull signal MPP, a sub push-pull signal SPP, and a differential push-pull signal DPP is executed. Then, a step of detecting a phase difference between the main push-pull signal MPP and the

10 differential push-pull signal DPP is executed. Furthermore, based on this phase difference, an offset is applied in the tracking control of the main beam with respect to the optical disk, thus compensating for any off-tracking caused by a phase shift of the differential push-pull signal DPP.

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INDUSTRIAL APPLICABILITY

According to the present invention, even in the case where an optical disk or an objective lens tilts along a radial direction of an optical disk, any off-tracking

20 occurring due to a phase difference between an MPP signal and

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an SPP signal can be corrected, thus enabling a stable

tracking control.   As a result, the recording/reproduction

performance of an optical pickup device can be improved.